

Does Anybody Really Know What Time It Is?

24/7/365, Here's How Time Got On Your Best Side

By Michael A. Lombardi

Occasionally I'll talk to people who can't believe that some radio stations exist solely to transmit accurate time. While they wouldn't poke fun at the Weather Channel or even a radio station that plays nothing but Garth Brooks records (imagine that), people often make jokes about time signal stations. They'll ask "Doesn't the programming get a little boring?" or "How does the announcer stay awake?" There have even been parodies of time signal stations. A recent Internet spoof of WWV contained zingers like "we'll be back with the time on WWV in just a minute, but first, here's another minute."

An episode of the animated *PowerPuff Girls* joined in the fun with a skit featuring a TV announcer named Sonny Dial who does promos for upcoming time announcements—"Welcome to the Time Channel where we give you up-to-the-minute time, twenty-four hours a day. Up next, the current time!"

Of course, after the laughter dies down, we all realize the importance of keeping accurate time. We live in the era of Internet FAQs, but the most frequently asked question in the real world is still "What time is it?" You might be surprised to learn that time signal stations have been answering this question for more than 100 years, making the transmission of time one of radio's first applications, and still one of the most important. Today, you can buy inexpensive radio-controlled clocks that never need to be set; some of us even wear them on our wrists.

Let's "go back in time" and look at the history of time signal stations, beginning with the first radio experiments and continuing to the present day.

The Early Days Of Time Signal Stations

Guglielmo Marconi is usually acknowledged as the inventor of radio, with an impressive list of achievements

known to most radio buffs. He used a spark-gap transmitter to successfully send radio signals over a distance of more than one mile in 1895. By 1899 he had transmitted signals across the English Channel, and sent signals across the Atlantic Ocean in 1901.

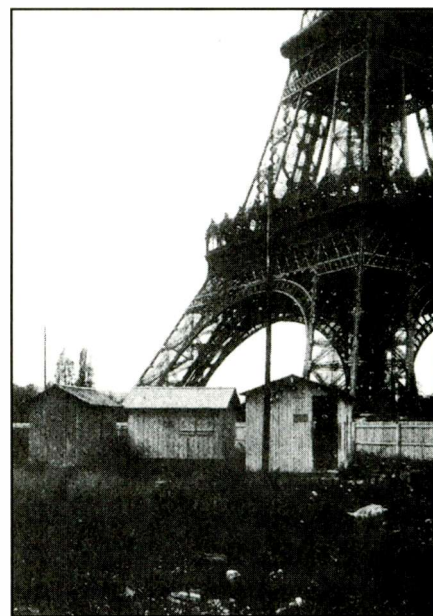
Surprisingly, in the midst of Marconi's early work, before any radio stations existed, or before the public even completely believed his results, a proposal was made to use the new wireless medium to broadcast time. In November 1898, an optical instrument maker and inventor named Sir Howard Grubb addressed the Royal Dublin Society and proposed the concept of a radio controlled clock. After many years of working with astronomical observatories, Grubb had developed a strong interest in timekeeping. After his talk, he published the following comments:

There is something very beautiful in this action of the "Marconi" wave. In a city supplied with this apparatus we should be conscious as we hear each hour strike that above us and around us, swiftly and silently, this electrical wave is passing, conscientiously doing its work, and setting each clock in each establishment absolutely right, without any physical connection whatsoever between the central distributing clock, and those which it keeps correct by means of this mysterious electrical wave.

We might go even still further, and although I do not put it forward as a proposition likely to be carried out in any way, except as an experiment, yet it undoubtedly would be perfectly possible to carry an apparatus in one's pocket, and have our watches automatically set by this electrical wave as we walk about the streets.

A true visionary, Grubb predicted the radio-controlled watch nearly 100 years before it finally appeared! Sharp-eyed readers might quibble that he described a pocket watch rather than a wristwatch, but keep in mind that men's wristwatches didn't appear until a few years later.

The "central distributing clock" that Grubb mentioned wasn't a new idea. Time signals had been distributed by tele-

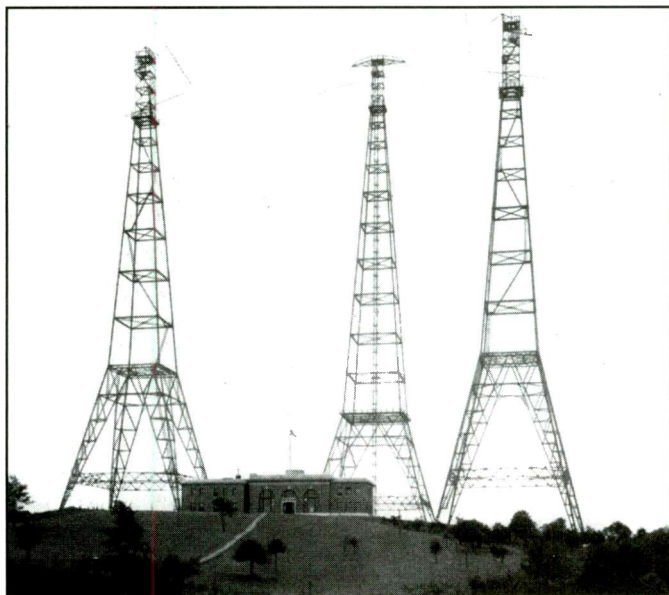


A photograph of the Eiffel Tower, published in 1909 prior to the start of the time broadcasts, which began in May 1910. It shows the small buildings at the base of the tower that housed the radio station equipment.

graph for decades prior to the invention of radio, since the telegraph had been invented around 1840. When the first time signal stations were built, the telegraph was used to send time from the reference clock to the broadcasting station.

The first radio time signal, sent by telegraphic code, was broadcast in September 1903 by the United States Navy. Most sources list Navesink, New Jersey, as the site of this broadcast, but the reference clock was located at the United States Naval Observatory (USNO) in Washington, D.C.

The first regularly scheduled time broadcasts began on August 9, 1904, from the Navy Yard in Boston. By the end of 1905, the Navy had transmitted time signals from stations in several other cities, including Norfolk, Newport, Cape Cod, Key West, Portsmouth, and Mare Island in California.



The three towers of the Arlington Virginia radio station where the NAA time signal originated. The tallest tower reached a height of about 183 meters, or about 14 meters taller than the nearby Washington Monument.

Sending time by radio was a hot technology in the early part of the 20th century, allowing time signals to be distributed everywhere, not just to places with access to the cumbersome land-lines used by telegraphs. There were countless benefits to having accurate time available, and railroad planners, ship navigators, military generals, business people, and others quickly became interested in the new technology.

Experimental time signal broadcasts were being tested in Switzerland and France as early as 1904, and patents for wireless time signal systems began arriving in the Swiss Patent Office by 1906, some passing across the desk of a young man named Albert Einstein. By 1907, Canada had begun to broadcast time from station VCS in Halifax, with signals referenced to the clock at St. John's Observatory.

High Atop The Eiffel Tower

The best known of the early time signal stations was FL in Paris, operated by the French Bureau of Longitude, which launched its signals from high atop the Eiffel Tower. Now one of the world's most famous monuments, the Eiffel Tower would have probably been demolished had it not proved to be useful as a radio tower. Then the world's tallest structure, the 312-meter tall tower was built in 1889 to help commemorate the centenary of the French Revolution. However, many Parisians had opposed its construction, and considered it unsightly. As a result, it was scheduled for demolition in 1909, when its 20-year lease finally expired. By 1904, however, the tower had become a station of the new French radio service, considered essential to the country's defense, and the now famous monument was spared.

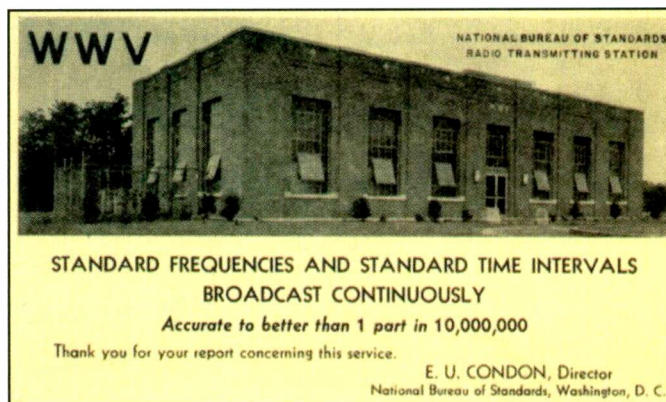
The Eiffel Tower time signal broadcasts began on May 23, 1910. The frequency of the original broadcast was near 150 kHz and the radiated power was about 40 kW. Time signals referenced to the clocks at the nearby Paris Observatory were sent twice daily. The signals spanned the Atlantic Ocean, reaching the United States and Canada and serving their intended purpose: to allow ships at sea to correct their marine chronometers.



WWV staff members assembled at the station's entrance in Beltsville, Maryland, in April 1943. This building was constructed after a November 1940 fire destroyed an earlier transmitter building located about three miles away.

Soon, many others began decoding the signals to obtain the correct time, including railroad companies, clock makers, jewelers, and others.

By June 1913, a regularly scheduled time service had begun. The frequency, format, and schedule for the time service was repeatedly changed, but the French somehow managed to keep the time service going through World War I and into the 1920s.



A WWV QSL card picturing the transmitter building in Beltsville, Maryland, and advertising frequency and time intervals to better than 1 part in 10 million. The exact date of this card is unknown, but 1945 is a good guess. That was the year that E.U. Condon became the NBS director, and also the year the telegraphic time code service began (note that the time code is not mentioned on the card).



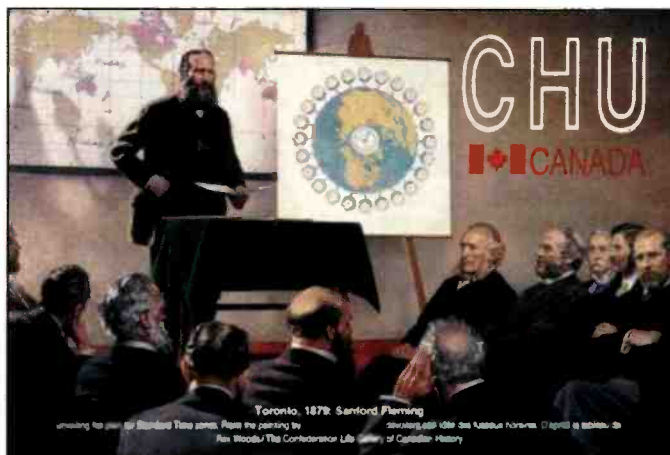
The QSL card sent today to listeners of NIST radio station WWVH which broadcasts from the island of Kauai in Hawaii. Reception has been confirmed in about 60 countries since 1990.

Today, the Eiffel Tower continues to be used as a mast for radio and television antennas.

Virginia's NAA

The American time signal station NAA began broadcasting time in 1913 from Fort Meyers in Arlington, Virginia. NAA used a rotary spark-gap transmitter at a frequency of 125 kHz and an output power of about 54 kW, making it the world's most powerful station.

The time came by wire from a USNO (US Naval Observatory) clock across the Potomac River, and was said to be accurate to "1/20 of a second" when it reached San Francisco. NAA was built as part of the U. S. Navy's effort to establish a worldwide communication network. The Arlington Radio Station includ-



The QSL card sent today to listeners of the Canadian time signal station CHU which broadcasts on three frequencies from a site near Ottawa. It features a painting of Sanford Fleming, whose contribution to the adoption of the present system of time zones earned him the title of "The Father of Standard Time."

ed three towers, with the tallest tower reaching a height of about 183 meters.

In 1915, engineers from American Telephone & Telegraph (AT&T) used the Arlington towers to send the first successful transoceanic voice communication, sending a message to a fellow American engineer who was listening in the Eiffel tower in Paris. It was only possible to send from west to east, so confirmation that the engineer's voice was heard was cabled back across the Atlantic.

By 1915, NAA was one of eight stations that made up the USNO's radio time service. Three stations (Arlington, Key West, and New Orleans) broadcast time controlled by the USNO clock in Washington, D.C.

How A Radio-Controlled Clock Works

Radio-controlled clocks contain both a miniature radio receiver and a traditional quartz clock. As a result, a typical WWVB clock contains two tiny quartz oscillators. One is a 32.768 kHz crystal that is used to control the timekeeping, the same type of oscillator you would find in any quartz watch or clock. The other is a 60 kHz crystal used to permanently tune the receiver to one frequency.

The receiver outputs a string of binary ones and zeros to a processing unit that decodes the signal and synchronizes the clock circuitry to the correct time. Because WWVB transmits UTC, the processing unit also applies a time zone correction to convert UTC to local time. This time zone setting is selected by the user, and must be changed if the clock is moved to a different time zone.

Building miniature antennas that work with longwave signals can be a challenge for receiver designers. Many radio-controlled clocks use ferrite loop antennas, consisting of a ferrite bar wrapped with a coil of fine wire, similar to what is found inside an AM radio.

In the case of wristwatches, the length of the ferrite bar is usually about 15 millimeters, and it must be hidden somewhere inside the watch. If the watch has a plastic or ceramic case this isn't a problem, but a metal case can block the signal. Some watches are partially metal, with the antenna hidden under-

neath a plastic panel near the connection to the watch band, or under the watch face.

Some radio-controlled clocks now work with more than one station. This usually means that they have more than one oscillator (a 60 KHz oscillator for WWVB and a 40 kHz oscillator for JJY, for example) but typically just one antenna. When a different station is selected, some designs match the antenna circuit to the antenna by varying the capacitance values. The size constraints make it difficult to build an antenna optimized for LF signals, so the goal is simply to get as much of the signal as possible, and to use the local oscillator and signal processing software to pull the time code out of the noise.

Most radio-controlled clocks only try to synchronize at night, because the signal is stronger and easier to receive after the sun goes down. Between synchs, the clock keeps time using its 32.768 kHz oscillator. Typically, the oscillator frequency is within a fraction of a hertz of its assigned value, which means it can keep time to within 1 second for a few days or more. Therefore, one synch per day is enough to make the clock appear to be on the right second, even though it has likely gained or lost a fraction of a second since the last synch. If the signal is not received the clock won't fail, but simply functions as an "uncontrolled" quartz clock.

Table 1. HF Time Signal Stations

Call Letters	Location	Frequency (MHz)	Language	Continuous Broadcast?
WWV	Fort Collins, Colorado	2.5, 5, 10, 15, 20	English	Yes
WWVH	Kauai, Hawaii	2.5, 5, 10, 15	English	Yes
CHU	Ottawa, Canada	3.33, 7.335, 14.67	French, English	Yes
BPM	Lintong, China	2.5, 5, 10, 15	Chinese	The 5 and 10 MHz signals are continuous, but 2.5 and 15 MHz only operate at scheduled times
HLA	Taejon, Korea	5	Korean	Yes
LOL	Buenos Aires, Argentina	5, 10	Spanish	No, currently only on from 1100 to 1200 Argentina Standard Time
YVTO	Caracas, Venezuela	5	Spanish	Yes

Five stations near the Pacific Ocean were used to broadcast the time maintained by a Navy clock at Mare Island. The signals were designed to be easy to decode. All eight stations would begin sending dots at 11:55 a.m., five minutes before noon. The dots were sent one second apart, with no signal sent on the 29th second of each minute, or during the last five seconds of each of the first four minutes. During the last minute before noon, the dots would stop 10 seconds before the end of the minute. A long dash was sent exactly at noon, serving as the on-time marker.

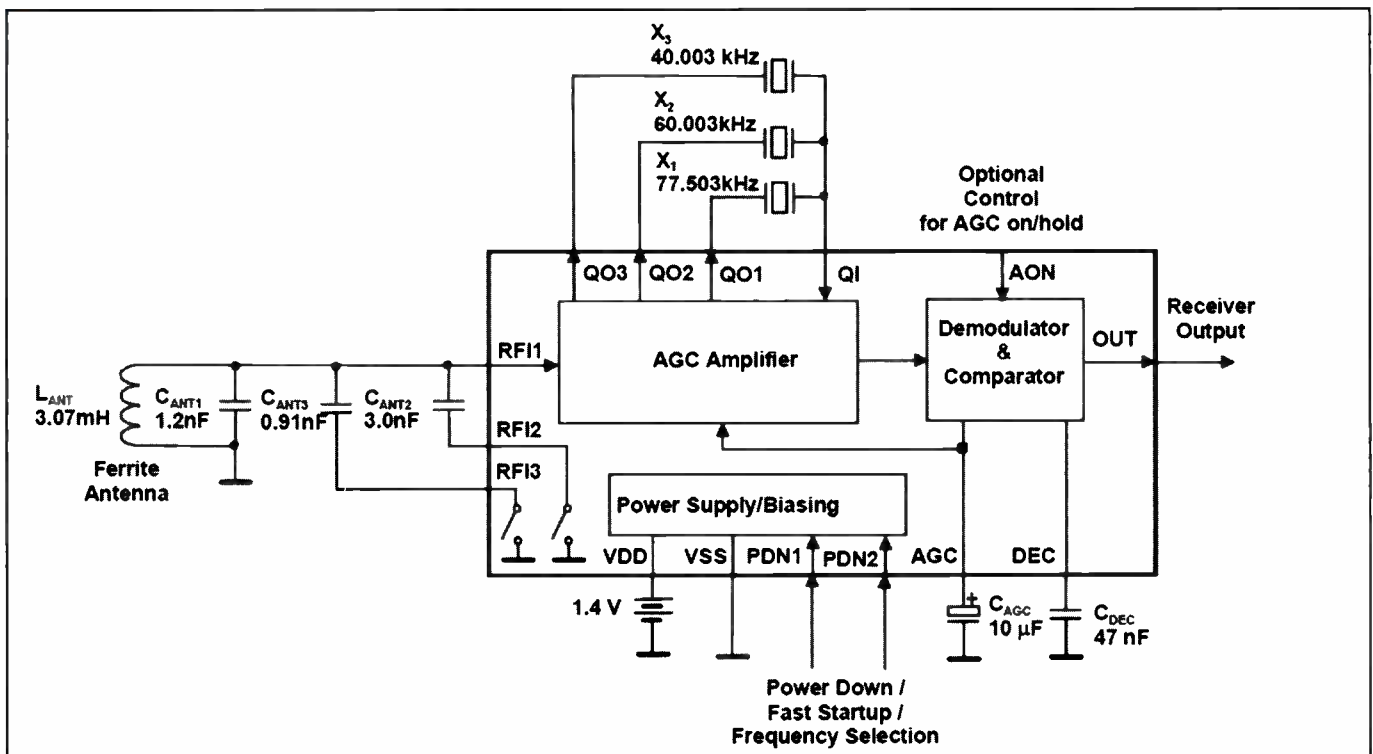
By 1924, NAA had switched to audio transmissions, and moved its operations to 690 kHz on the then new AM broadcast band. The historic Arlington towers were dismantled in

1941 because they were considered a hazard to aircraft approaching the new Washington National Airport.

The USNO's radio time service was overtaken during World War II by the time broadcasts of the National Bureau of Standards (discussed in the next section), but the NAA callsign lives on. Since 1961 it has been assigned to a megawatt VLF station in Cutler, Maine, that the U.S. Navy uses to communicate with submarines.

WWV Solves The Frequency Problem

The National Institute of Standards and Technology (NIST), formerly called the National Bureau of Standards (NBS), orig-



Sample circuit diagram for a radio-controlled watch chip that works with four different time signal stations. The circuit includes three crystal oscillators and a single antenna with a capacitance matching array. The 40 kHz crystal is for JJY, the 60 kHz crystal is for JJY, MSF, and WWVB, and the 77.5 kHz crystal is for DCF77. The chip can demodulate all four time codes. Note that the crystal filter circuit does not include a loading capacitor, so the nominal frequency of each crystal should be a few hertz high in order for the circuit to resonate at the time signal carrier frequency (circuit courtesy of Micro Analog Systems).

Table 2. LF Time Signal Stations

Call Letters	Location	Frequency (kHz)	Controlling Agency
WWVB	Fort Collins, Colorado, United States	60	National Institute of Standards and Technology (NIST)
BPC	Lintong, China	68.5	National Time Service Center (NTSC), Chinese Academy of Sciences
DCF77	Mainflingen, Germany	77.5	Physikalisch-Technische Bundesanstalt (PTB)
HBG	Prangins, Switzerland	75	Swiss Federal Office of Metrology and Accreditation (METAS)
JJY	Japan	40 and 60	National Institute of Information and Communications Technology (NICT)
MSF	Rugby, United Kingdom	60	National Physical Laboratory (NPL)
RBU	Moscow, Russia	66.67	Institute of Metrology for Time and Space (IMVP)

inated in 1901 and was involved in radio research by 1905. However, the agency did not get involved in the time keeping business immediately, but instead focused its early efforts on developing frequency standards, eventually broadcasting standard frequencies from radio station WWV.

WWV began broadcasting in May 1920 from Washington, D.C. at a frequency of 600 kHz. Ironically, the first broadcasts consisted of Friday evening music concerts that lasted from 8:30 to 11:00 p.m. The station's 50 watt signal could be heard about 40 kilometers away.

Other uses of the station followed, but by late 1922, it was decided that the station's purpose would be to transmit standard frequencies that provided a reference signal for other radio broadcasters. By March 1923, WWV was broadcasting frequencies from 125 to 2000 kHz on a monthly or weekly schedule. The accuracy of the transmitted frequency was said to be "better than three-tenths of one per cent."

During WWV's early days, the transmitter was adjusted to the correct frequency using a wavemeter, which was checked against the national standard immediately before being brought

to the station. However, the recently invented quartz oscillator soon became the national standard of frequency.

By 1927, a 50 kHz temperature-controlled quartz oscillator was installed at the station site. During the transmission, the frequency of the transmitter was held manually so that no beat note was audible between the transmitter and the quartz oscillator.

New radio stations were being built across the United States throughout the 1920s, and the radio industry desperately needed a reliable reference standard for frequency. If the new stations couldn't stay near their assigned frequencies, the airwaves would be unusable. To meet the needs of the fast growing radio industry, WWV was continuously evolving, adding more frequencies, increasing its coverage area, and increasing the accuracy of its standard frequencies, which was reduced to less than 1 part per million by the early 1930s.

It wasn't until 1937, however, when WWV began to transmit time. Originally, all that was sent were seconds pulses that served as a time interval reference. The pulses were not held in phase with any time reference, because the United States Navy still served as the nation's official radio time broadcaster. This



An aerial photograph of the site shared by WWV and WWVB near Fort Collins, Colorado, taken during the 1990s. The relatively small WWV antennas aren't visible from this angle, but the eight large towers support the massive WWVB antenna array.



The interior of a low cost watch controlled by WWVB signals. Note the ferrite bar antenna and two crystal oscillators, one a 32.768 kHz crystal that drives the quartz clock, the other is a 60 kHz crystal that serves as a pre-selector for the time signal. The battery appears to take up more area than the crystals and antenna combined.

changed in June 1944, when the Superintendent of the USNO authorized the synchronization of the WWV time signals to those of the USNO, largely because the Navy had ordered the USNO to cut back time transmissions during World War II. As a result, WWV began sending time messages in telegraphic code every five minutes in October 1945.

The famous voice announcements of time, now known to nearly all who listen to shortwave radio, began on January 1, 1950. By the 1960s, WWV and other time signal stations were controlled by atomic oscillators, and today most stations are referenced to frequency standards accurate to better than 1 part per trillion, although their received accuracy can be much less due to radio propagation noise.

Today's Time Is . . .

WWV moved to its current site in Fort Collins, Colorado, in 1966 and continues to broadcast standard time and frequency information on 2.5, 5, 10, 15, and 20 MHz. A sister station, WWVH, began operation in Hawaii in 1948, adding voice announcements of time in 1964.

Today, WWVH shares all of the WWV frequencies with the exception of 20 MHz, and it is often possible to hear both stations. It's easy to tell the difference, because a man's voice announces the time on WWV, and a woman's voice is used on WWVH. The WWV announcement begins about seven seconds prior to the top of the minute, and the WWVH announcement begins about 15 seconds prior to the top of the minute (lasting for about seven seconds), so the two announcements never overlap.

HF Time Signal Stations: Talking Clocks

WWV and WWVH aren't the only "talking clocks" found on the shortwave bands. The Canadian station CHU is normally an easy catch for U.S. listeners on 3.33, 7.335, and 14.67 MHz, with voice announcements of time made in both French and English. An official source of time in Canada, it is believed that CHU began broadcasting time in 1929, and has done so since 1938 using the current call letters.

Table 1 lists other HF time stations, most sharing the WWV and WWVH frequencies, which are internationally allo-

cated for standard time and frequency broadcasts. Note that the ranks of the HF time stations have thinned recently, with stations such as IAM in Italy, VNG in Australia, JJY in Japan (the call letters were transferred to the LF station), ATA in India, and BSF in Taiwan all going off the air since 1998.

The HF time stations produce the world's most accurate voice announcements of time. Although some HF time signal stations (including WWV and WWVH) broadcast a time code, nearly all inexpensive radio-controlled clocks receive signals from the LF time signal stations that we'll discuss next. The LF stations lack the bandwidth to send any voice announcements at all, but their time codes are easy to receive indoors and outdoors with small antennas, making them perfectly suited for synchronizing radio-controlled clocks.

LF Time Signal Stations And Those Popular "Atomic" Clocks

Low-cost radio-controlled clocks first appeared in the early 1990s. Today they

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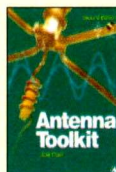
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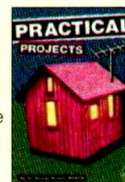


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Practical Projects

Edited by Dr. George Brown, M5ACN
RSGB 2002 Ed, 224 pages

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RSGB. 2nd Ed, 1996. 160 pages.

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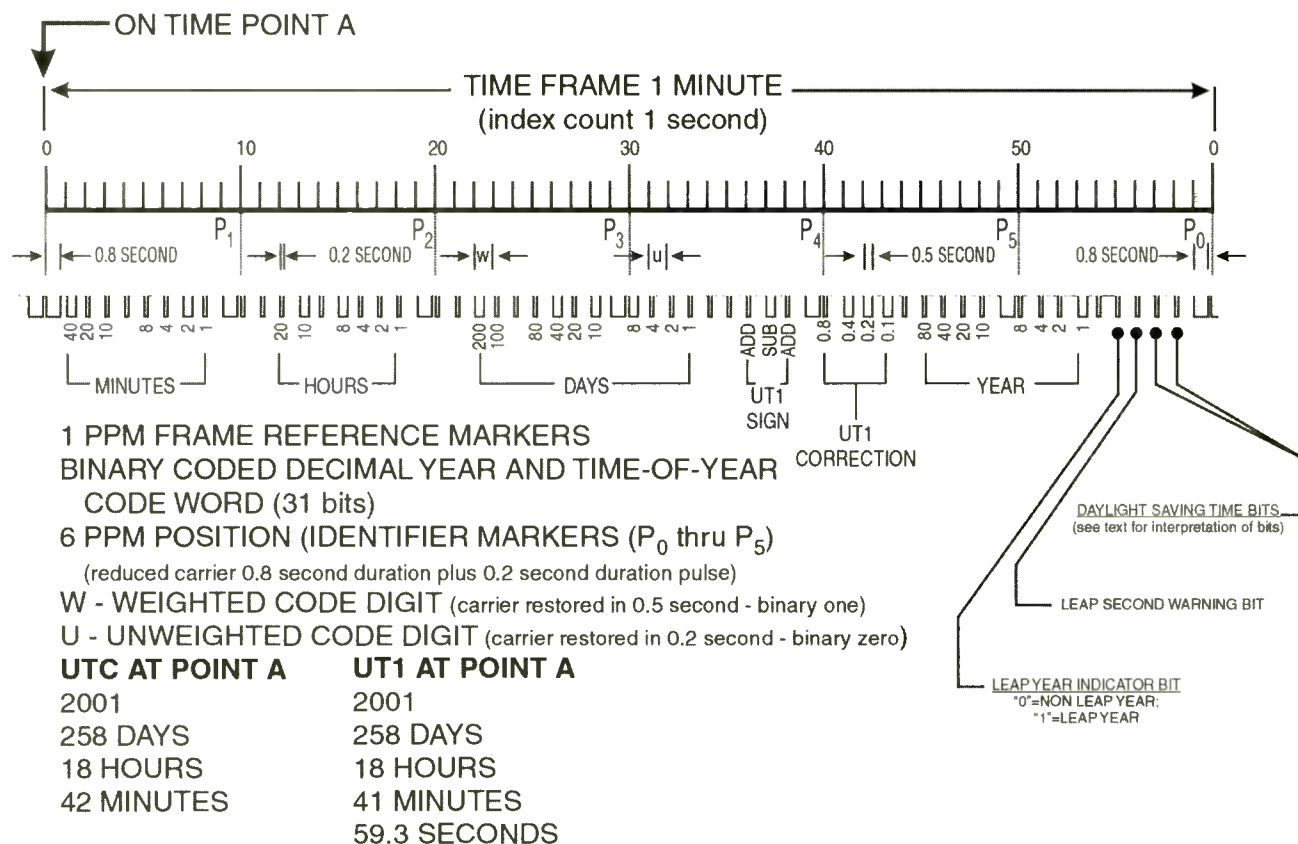
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WWVB TIME CODE FORMAT



The time code format used by WWVB and now read by millions of radio-controlled clocks. The time code is sent continuously at a rate of 1 bit per second, with a complete time code sent every minute.

are found in retail stores throughout the United States, Asia, and Europe, and millions of units are sold annually. These clocks receive signals in the 40 to 80 kHz range, located in the LF part of the radio spectrum, the same band used by early stations like FL and NAA. Although LF communications is far from a new technology, it remains perfectly suited for time signals, where only a small amount of information is sent and little bandwidth is required.

Sometimes called longwave stations (the wavelength of 60 kHz is 5 kilometers, or more than three miles), LF stations (see **Table 2**) can cover a wide area with relatively low power. Even more importantly, their signals can be received indoors with simple antennas, because they easily pass through non-metallic buildings and walls. This gives them an edge over other time signals, such as those from the GPS satellites, which are hard to receive indoors.

All LF time signal stations are run by standards laboratories that keep the official time in their respective countries, so the time signal as broadcast is usually exceptionally accurate. The time code sent by the station normally contains the hour, minute, second, date, daylight saving time notification, and other information. All stations use a different time code format, but many radio-controlled clocks now work with more than one station, because the carrier frequencies and modulation schemes are similar. As a result, you can now buy a radio-controlled wristwatch that will synchronize in the United States, Asia, and Europe.

Future products should work in even more places, because in sharp contrast to the HF stations, the number of LF stations is expected to grow. To meet the anticipated demand for radio-controlled clocks, several countries are planning to build new LF time signal stations.

WWVB, Time Source For The United States

Most radio-controlled clocks in the United States are controlled by WWVB, which shares a sprawling 390 acre site with WWV near Fort Collins, Colorado. WWVB continuously broadcasts a 50 kW signal at 60 kHz that is strong enough during the nighttime hours to reach all 50 states. The antenna array is immense, covering about 30 acres and suspended from towers 122 meters tall, but the modulation technique is simple.

Time signals are sent by raising and lowering the power of the carrier frequency. The 60 kHz carrier frequency is locked to a cesium oscillator whose frequency is continuously steered to agree with the national frequency standard located in nearby Boulder, Colorado. A time code generator synchronized to Coordinated Universal Time (UTC) modulates the signal once per second by dropping the carrier power. If full power is restored 0.2 seconds later, it represents a 0 bit; if full power is restored 0.5 seconds later, it represents a 1 bit. A frame marker is sent by dropping the power for 0.8 seconds. The time code

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generator signal is sent to the transmitter, which amplifies the signal and sends it to the antenna array.

Although this form of modulation is sometimes called amplitude shift keying, it is more properly referred to as pulse width modulation by reduced carrier transmission. This is because the information contained in the signal is demodulated by looking at the pulse widths (duration) and not by looking at the amplitude. Most LF time signal stations use a similar method to modulate their time code (the one exception is RBU in Moscow which uses an AM subcarrier).

In today's world of high-speed communications, it's interesting to note that WWVB sends time at a glacial rate of 1 bit per second (imagine sending an e-mail or fax at that speed!). Even so, a full time code is sent each minute, and the signal requires very little bandwidth to transmit. Technically, the bandwidth requirement is just 5 Hz, but due to the nature of the transmission and antenna system, the station has a bandwidth allocation of 2 kHz, of which about 600 Hz is currently used. Another advantage is that very little processing power is required to keep up with the bits and read the time.

Suggested Reading

Steven J. Dick, *Sky and Ocean Joined, The U.S. Naval Observatory 1830–2000* (Cambridge University Press, 2003)

Tony Jones, *Splitting the Second: The Story of Atomic Time* (Institute of Physics Publishing, 2000)

Peter Gallison, *Einstein's Clocks, Poincare's Maps* (W. W. Norton & Company, 2003)

Gavin Weightman, *Signor Marconi's Magic Box* (Da Capo Press, 2003)

NIST Time and Frequency Services, NIST Special Publication 432, 2002 (available for download from <http://tf.nist.gov/general/pdf/1383.pdf>)

NIST Time and Frequency Radio Stations: WWV, WWVH, and WWVB, NIST Special Publication 250-67, 2005 (available for download from <http://tf.nist.gov/general/pdf/1969.pdf>)

WWVB Radio Controlled Clocks: Recommended Practices for Manufacturers and Consumers, NIST Special Publication 960-14, 2005 (available for download from <http://tf.nist.gov/general/pdf/1976.pdf>)

So the next time somebody makes a joke about time signal stations, go ahead and laugh politely. Then inform them that time signal stations have been around for more than 100 years, and that they control millions of clocks that never need to

be set. Because after all, many of us now expect our clocks to be on time, all the time, and can envision a day when every clock is "absolutely right," making the more than century-old vision of Sir Howard Grubb a reality. ■

Michael Lombardi serves as the quality manager for the NIST Time and Frequency Division, the organization that operates radio stations WWV, WWVH, and WWVB. He can be reached at lombardi@nist.gov.